

# The Equation of State of Nuclear Matter in Heavy Ion Collisions at CERN-SPS Energies from the Viewpoint of Relativistic Hydrodynamics

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We present refits of single inclusive cross section data of mesons and baryons for central 158 *AGeV* Pb+Pb collisions measured by the NA44 and NA49 Collaborations. In the theoretical approach we use the relativistic hydrodynamical code HYLANDER-C. We investigate several equations of state in their capability to describe the measured single inclusive momentum distributions. Based on the obtained fits we present results of the calculated Bose-Einstein correlation functions of identical pion pairs and discuss their features in comparison to measurements.

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# The Model: HYLANDER-C

Improved version of **HYLANDER**.

U. Ornik, F. Pottag, R.M. Weiner,  
Phys. Rev. Lett. 63, 2641 (1989).

## Numerical Solution of the Hydrodynamical EULER Equations

$$1. \quad \partial_t E = -\vec{\nabla} \cdot \vec{M}$$

$$2. \quad \partial_t M_i = -(\vec{\nabla} \cdot (M_i \vec{v}) + \partial_i P)$$

$$3. \quad \partial_t B = -\vec{\nabla} \cdot (B \vec{v})$$

## Direct Use of an Equation of State (EOS)

$$4. \quad P(\epsilon, n) = c^2(\epsilon, n) \epsilon$$

## Useful Relations

$$(a) \quad P/\epsilon = c^2(\epsilon) = \frac{1}{\epsilon} \int_0^\epsilon c_o^2(\epsilon') d\epsilon'$$

$$(b) \quad T(\epsilon) = T_c \exp \left[ \int_{\epsilon_c}^\epsilon \frac{c_o^2(\epsilon') d\epsilon'}{(1 + c^2(\epsilon')) \epsilon'} \right]$$

# Input for HYLANDER-C

## Type of EOS

Any type of EOS can be used.

1. in tabular form.

2. through parametrization.

(a) K. Redlich, H. Satz,  
Phys. Rev. D33, 3747 (1986).

→ I

(b) C.M. Hung, E.V. Shuryak,  
Phys. Rev. Lett. 75, 4003 (1995).

→ II

(c) H. Sorge,  
“Soft transverse expansion in Pb(158 AGeV) on  
Pb collisions: preequilibrium motion or 1st order  
phase transition?”,  
(1997) SUNY-NTG 97-1, nucl-th/9701012.

→ III

## Initial Conditions

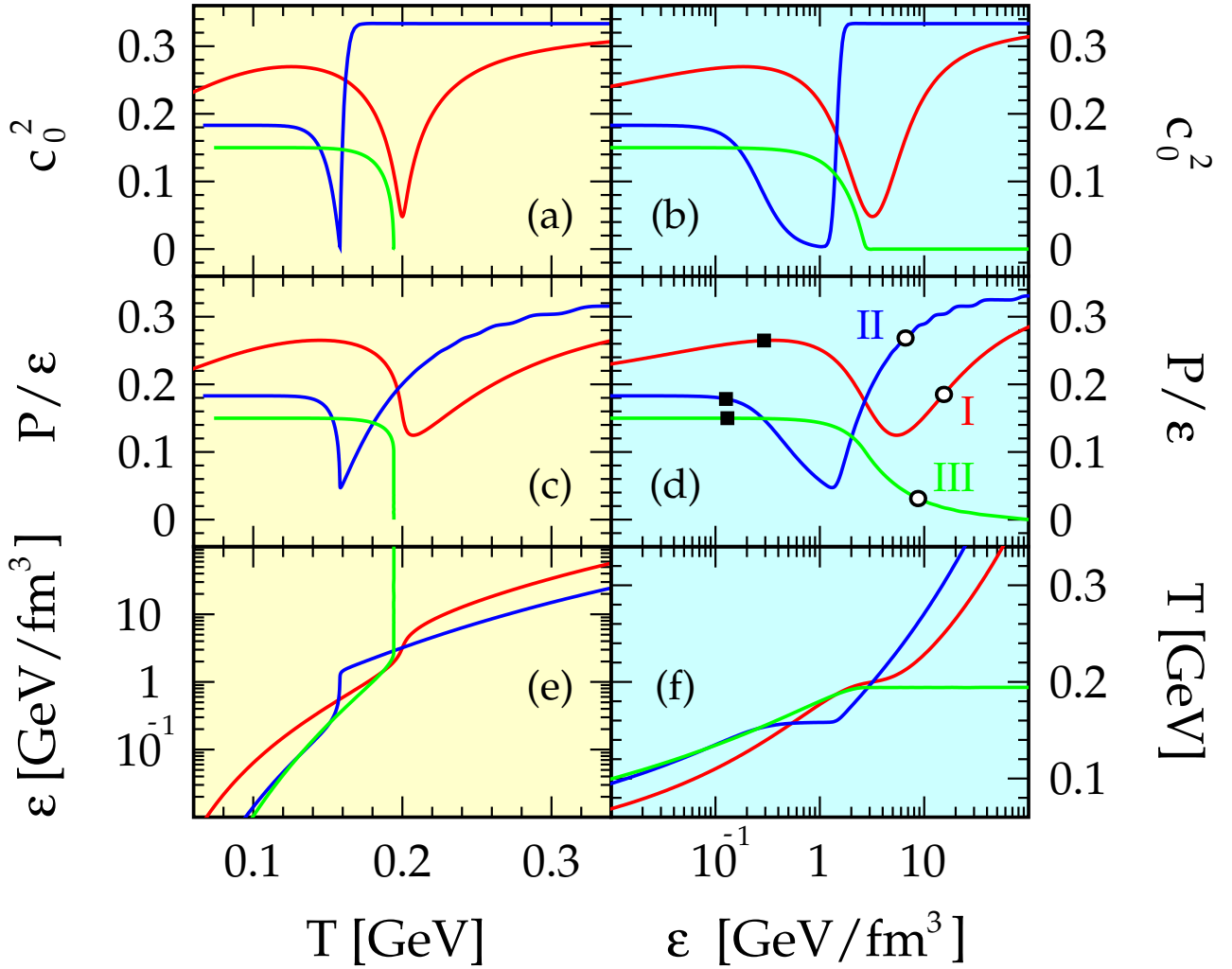
Any type of initial conditions can be used.

1. in tabular form.

2. through parametrization.

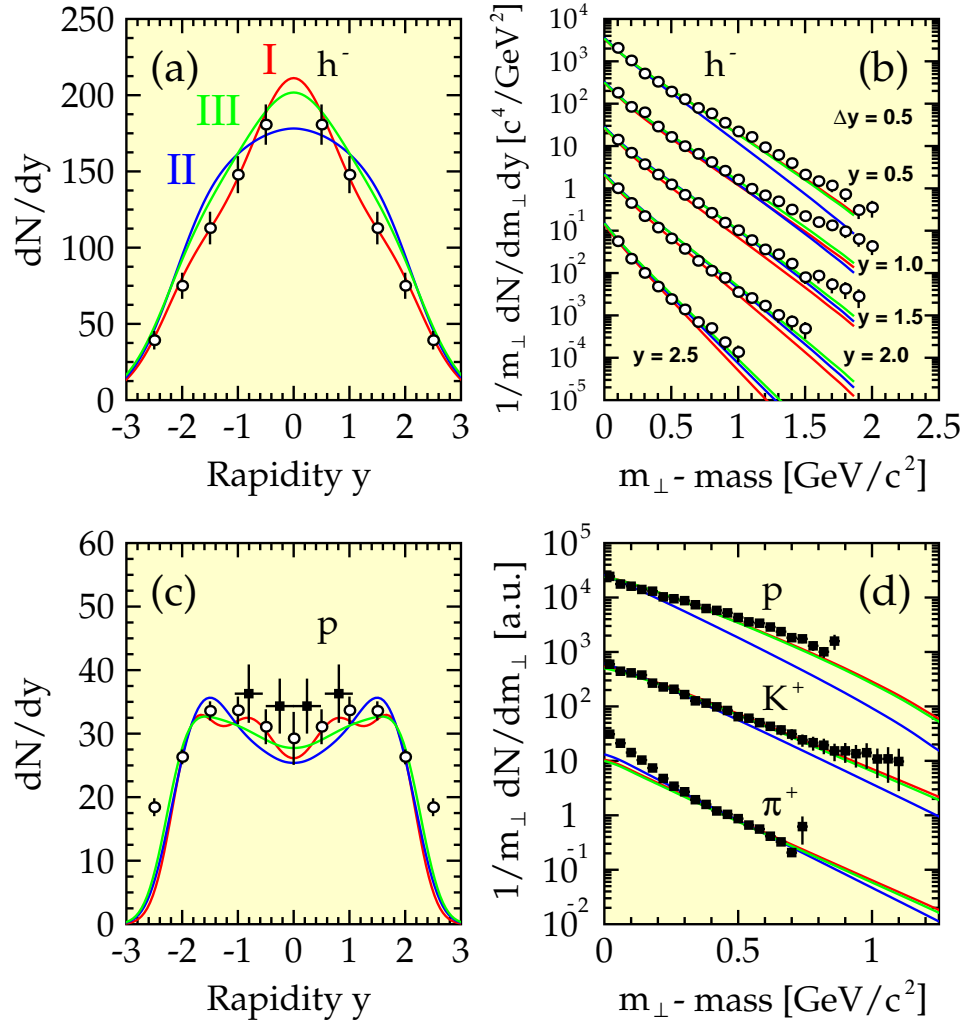
(a) J. Bolz, U. Ornik, R.M. Weiner,  
Phys. Rev. C46, 2047 (1992).

# Equations of State



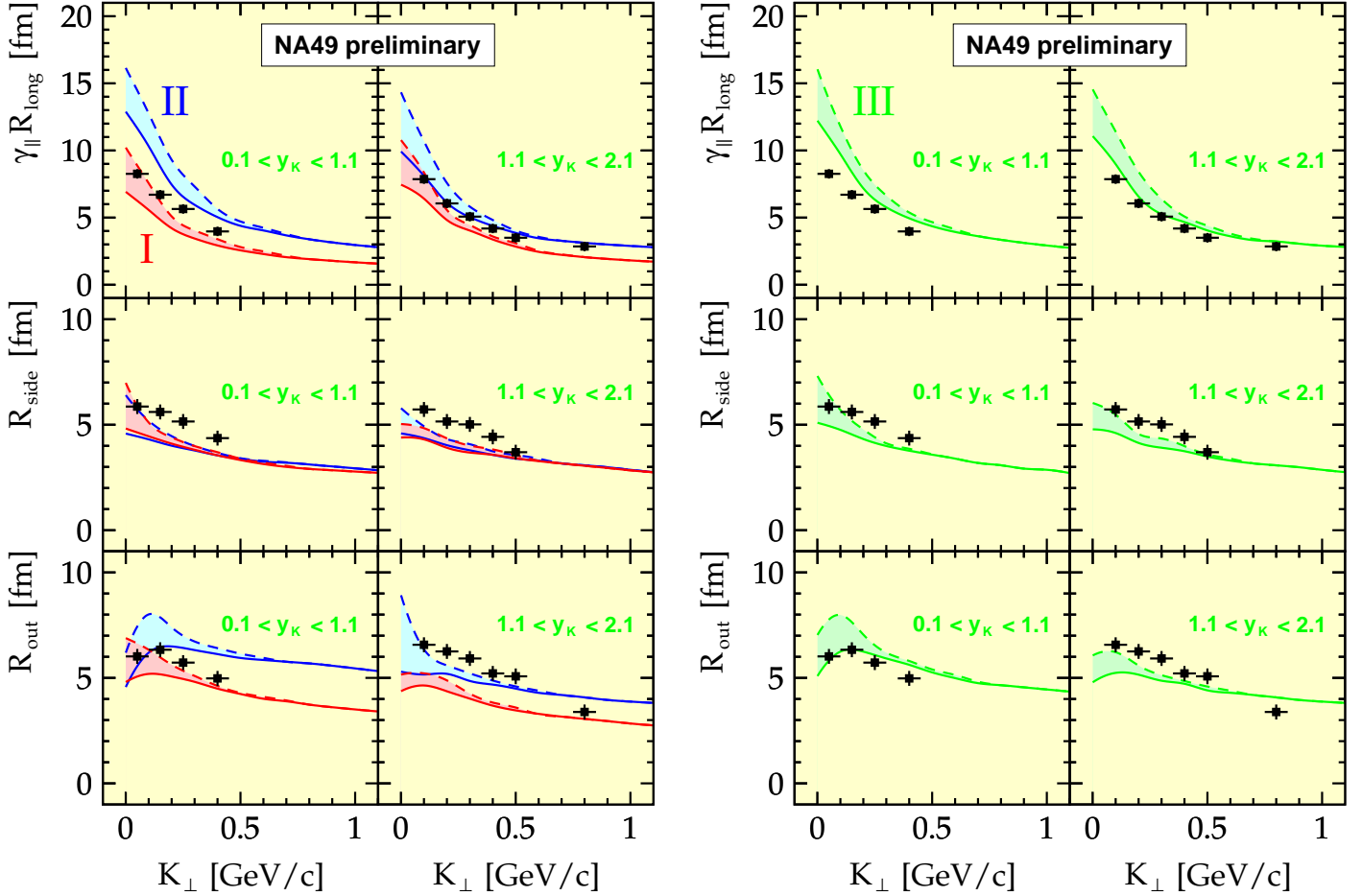
Energy density,  $\epsilon$ , ratio of pressure and energy density,  $P/\epsilon$ , speed of sound,  $c_0^2$ , and temperature,  $T$ , as functions of  $T$  and/or  $\epsilon$ , for the equations of state EOS-I (red lines), EOS-II (blue lines), and EOS-III (green lines), respectively. The open circles in plot (d) correspond for each EOS to the starting values of  $P/\epsilon$  with respect to the achieved initial maximum energy density  $\epsilon_\Delta$  at transverse position  $r_\perp = 0$ , whereas the filled squares represent the final values of  $P/\epsilon$  at breakup energy densities,  $\epsilon_f$ .

# Single Inclusive Distributions



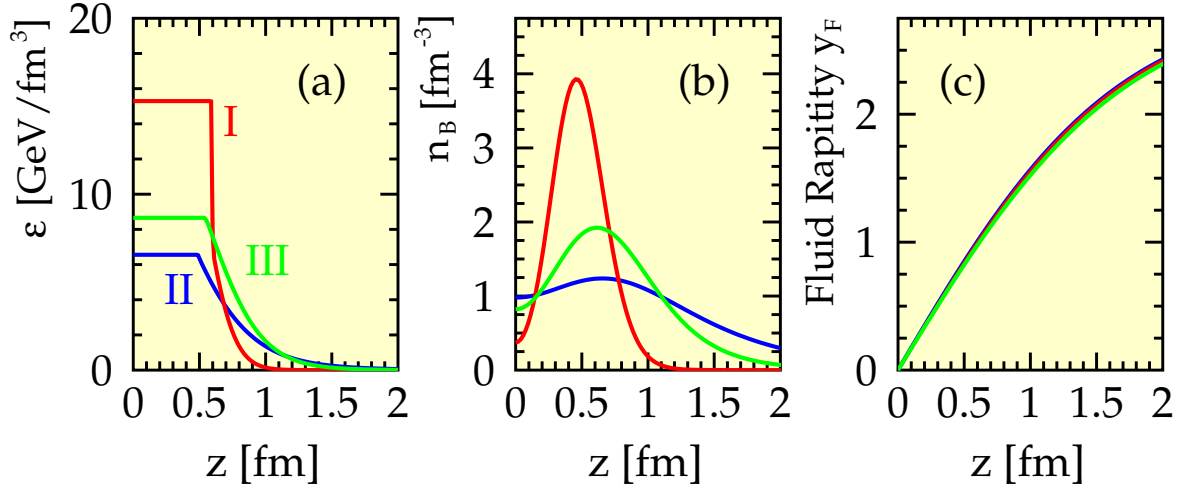
(a) Rapidity spectra and (b) transverse mass spectra,  $1/m_{\perp} dN/dm_{\perp} dy$ , of negative hadrons,  $h^-$ , (c) rapidity spectra of protons (without contributions from  $\Lambda^0$  decay) and (d) transverse mass spectra,  $1/m_{\perp} dN/dm_{\perp}$ , of protons (including contributions from  $\Lambda^0$  decay),  $p$ , positive kaons,  $K^+$ , and positive pions,  $\pi^+$ , respectively. The red (blue (green)) lines indicate the results of the calculations when using equation of state EOS-I (EOS-II (EOS-III)). The open circles represent preliminary data taken by the NA49 Collaboration, whereas the filled squares represent final data taken by the NA44 Collaboration.

# Bose-Einstein Correlations



Inverse widths of BEC functions of identical negative pion pairs (including decay contributions from resonances) as functions of the average transverse momentum of the boson pair,  $K_{\perp}$ , in the indicated ranges of the particle pair rapidities,  $y_K$ , compared to preliminary data of the NA49 Collaboration. The solid lines indicate the inverse widths of BEC functions extracted from a Gaussian fit for the calculation using EOS-I (EOS-II (EOS-III)). The dashed lines are the true inverse widths of the correlation functions at their 68% level, and the colored zones reflect the theoretical uncertainties, when extracting the inverse widths.

# Results



Initial distributions of (a) the energy density,  $\epsilon$ , (b) the baryon density,  $n_B$ , and (c) the fluid rapidity,  $y_F$ , plotted against the longitudinal coordinate  $z$  at transverse position  $r_\perp = 0$ . The red (blue (green)) lines indicate the initial distributions for the calculation using EOS-I (EOS-II (EOS-III)).

## Special Features

1. FULL THREE-DIMENSIONAL SOLUTIONS
2. TRANSVERSE EXPANSION
3. EFFECTS OF RESONANCE DECAY
4. FREEZE-OUT TEMPERATURE,  $T_f = 139\text{MeV}$

## References

B.R. Schlei, Heavy Ion Phys. 5 (1997) 403.

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Los Alamos Preprint LA-UR-97-4230.